The study of Improvement of Quality Control for the Reduction of Pavement Deterioration

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ABSTRACT

There are various causes that may deteriorate asphalt pavement. Main causes, among them, are displayed by under-qualified quality control at plant and in-place density control. Therefore, comprehensive investigations of actual condition of quality control at plants and in the field were conducted for the purpose of improvement of quality control and finding errors at each process. With the result of investigation of control condition of flat or elongated particles in aggregates, 33% of the highest grade, 40% of the second grade, 27% of the third grade was classified. This classification indicates insufficient control of flat or elongated particles in aggregates. Yet density and absorption or of aggregates nearly meet the requirement at 6 plants. Aggregate gradation of 2 plants out of 7 plants meet the specification criteria, but 5 plants were out of the specification criteria at cold bins. In case of hot bin, none of them meet the specification criteria, by 5 plants were kin to the specification criteria. Comparing the mix report from local plants with lab test result, there were difference in between theoretical density and measured density, which causes deviation up to 2.3% in air-void. Further, 5 plants were out of allowable error when the verification of in-place test result was done. Maximum 2.1% of air-void difference was found while analysing deviation in between test devices for maximum theoretical density.

Analysing from actual condition of in-place density control, in-place density requirements; however, it was found that quality control in the field was insufficient because lab test result of mix from 2 plants failed to match requirement. The method for in place density measurement was developed, and it was found that in-place applicability was sufficient with 0.5% error comparing lab test result.

4 processes in need of quality control improvement were found by comprehensive analysis. Air-void, flat or elongated particles of aggregates, aggregates gradation, in-place density control were found in order of insufficient quality control.

1. Introduction

Asphalt pavements are designed to have ten-year service life, but the average life of road pavements is heavily affected by high temperature and heavy rainfall during the summer. These factors cause crack, plastic deformation, and pot-hole to the road pavement. A combination of recent increase in the number of heavy vehicles and the declining environmental conditions, which imposes difficulties in using natural aggregates, is harming the durability of pavement. Technological aspect such as quality control is not making much progress and early damages to the pavement are frequent as well.

Early damages to the pavement result in increased maintenance cost and serve as a degrading factor to traffic safety, increasing the social cost in return. There have been efforts to improve technological aspects of the issue such as asphalt pavement mix design, broader criteria, and a new manual. However, construction-oriented activities rather than the quality control-focused are hindering technological development.

The aggregates used for asphalt pavements must satisfy stricter criteria in terms of shape and gradation than concrete aggregates. However, only three percent of the total aggregate production volume are used for asphalt pavement aggregates. For this, aggregate manufacturers are avoiding the manufacturing of single-grade aggregates that are suitable for asphalt pavements. To create asphalt pavements that can maintain serviceability until the end of design life, all stages from mix design, manufacturing of asphalt mixture, to paving and compacting the field must be thoroughly managed, but quality control is inadequate due to the lack of professionals with the expertise of the field.

The objective of this study is to discover and analyze the factors that can affect the quality control of asphalt pavement from mix design, manufacturing of asphalt mixture, and test construction to perform preventive quality control that will reduce pavement damages.

In this study, the same samples used throughout the entire asphalt pavement construction process in the plants and the results of an experiment stated on supply source approval form provided by the plants were analyzed and compared with the lab test results. A survey research on the issues involved with operating the plant was taken on plant staffs as well. For the research, seven locations per region were selected and studied as shown in Figure 1.

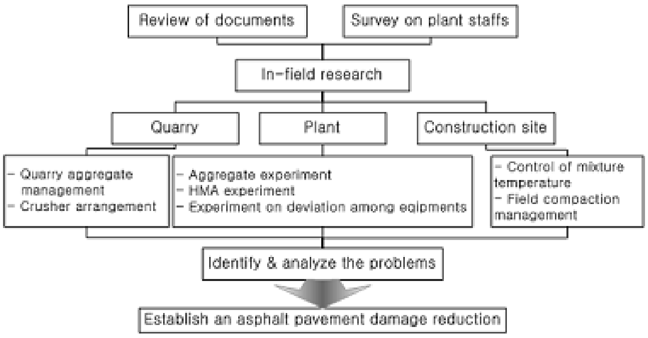


Fig. 1 Procedures Used in the Study

2. Indoor Experiment on In-Field Aggregates by Region

2.1 Experiment on flat or elongated particles and the results

Experiments on aggregates conducted were flat or elongated particles test, density and absorptance test, and the cold bin and hot bin test for each size of the aggregates. 15 types of aggregates from seven locations were used as samples (nine crushed stones, six SMA aggregates). The samples were analyzed as shown in Table 1.

Of the seven locations, B, C, and E had less flat or elongated particles in aggregates but were analyzed to have sound quality control of SMA aggregates.

Locations F and G showed a large difference between the experiment results from the plant and the lab.

Table 1 Flat or Elongated Particle Test in Different Locations

Classification \ Location		Average Ratio of Flat or Elongated Particles (%)							
		A	B	C	D	E	F	G	Mean
13mm	Plant	6.4	-	-	-	-	7.3	1.5	5.1
	Lab	16.1	8.1	-	-	10.6	24.2	29.7	17.7
19mm	Plant	-	-	-	-	-	7.5	2.4	5.0
	Lab	-	-	-	-	20.0	29.5	19.9	23.1
25mm	Plant	-	-	-	-	-	-	1.5	1.5
	Lab	-	-	-	-	-	-	20.1	20.1
10mm SMA	Plant	-	-	-	-	4.6	-	-	4.6
	Lab	-	-	1.2	-	8.2	-	-	4.7
13mm SMA	Plant	-	-	-	15.8	5.7	-	-	10.8
	Lab	-	-	2.7	10.6	5.7	-	-	6.3
19mm SMA	Plant	-	-	-	13.9	-	-	-	13.9
	Lab	-	-	-	19.9	-	-	-	19.9

2.2 Aggregate density and absorptance test

The tests on the density and absorptance of coarse aggregates collected from different locations were conducted in accordance with the KS F 2503, and the tests on the density and absorptance of fine aggregates were conducted in accordance with the KS F 2504.

20 aggregates were collected from seven locations for the analysis. The density of coarse and fine aggregates analyzed in this study satisfied the standard 2.5 except for the aggregates smaller than 6mm collected from the location C.

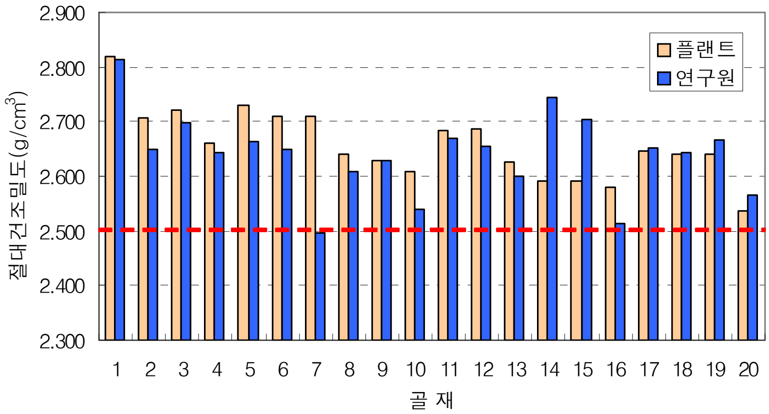
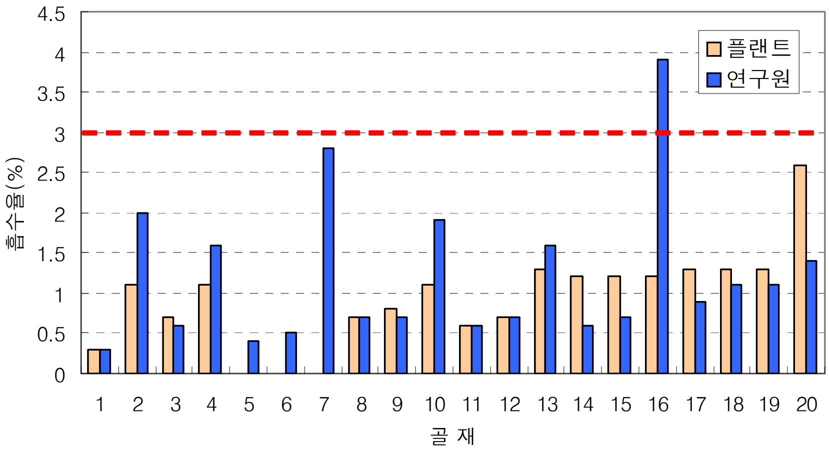


Fig 2 Aggregate Density Test (Plant vs Lab)

The analyzed absorptance of coarse and fine aggregates showed most to have a value below the standard 3.0%, but aggregates smaller than 6mm from the location F had 3.9%, which deviates from the specification.

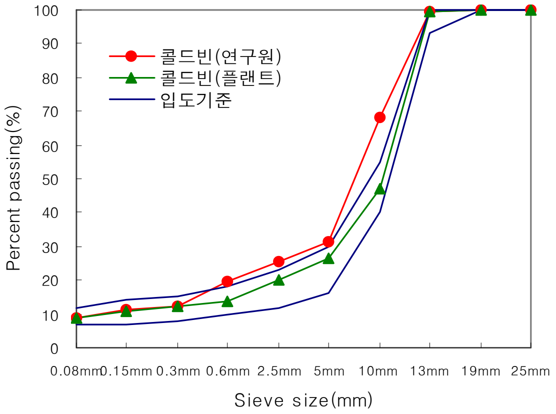


2.3 Test on the aggregate size

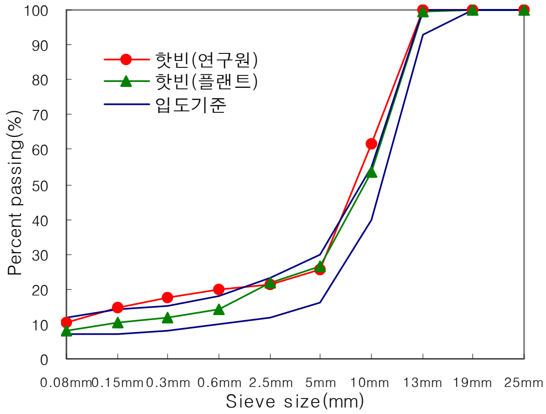
Changes in the size of cold bin aggregates not only cause changes in the size of hot bins but also the overflow. To cope with this, asphalt plant managers adjust the cold bin VS motor and changes the size of hot bin aggregates. This results in manufacturing of mixtures completely different from the intended mixtures. In order to minimize the issue of overflow, efforts need to be made to prevent changes in the size of aggregates inserted to cold bins, check if the hot screen is in a normal condition when changes in the size of hot bin are severe, and test the cold bin aggregates and examine the flow.

In this study, the tests on the size of aggregates were compared and analyzed using the sieve analysis conducted in the lab with aggregates of cold and hot bins used in mix design for each

location. Figure 4 is an example of the difference in results between the tests conducted in plant and the lab.



a. Cold Bin Sieve Size



b. Hot Bin Sieve Size

Fig 4 Comparison of Aggregate Size Curves in Location E

The result of analysis on the size showed that two locations (C and D) satisfy the size specification and five other locations (A, B, E, F, and G) do not meet the specification. This phenomenon is likely to occur when the size of the aggregates supplied to cold bin is not single-grade. In case of hot bin, all locations failed to meet the specification but the five locations (A, B, D, F, and G) had relatively similar size as the specification. If the specification cannot be satisfied by mixing cold bin aggregates, it is likewise difficult to meet the specification by mixing aggregate sizes in hot bin. Therefore, aggregates stored in each cold bin must be of single-grade.

When the sizes of cold and hot bins cannot be managed as described above, a mixture completely different from the designed mixture can result. Therefore, asphalt plants should use single-grade aggregates and perform flow test to constantly monitor the changes in the size of cold and hot bins to manufacture asphalt mixtures of desired size.

3. Asphalt Mixture Property Test by Location

For the asphalt mixture test, mixtures produced on the same day were collected then compared and analyzed with the results of specimen density and maximum theoretical density tests. The same mixtures were also manufactured to compare and analyze the deviation among maximum theoretical density equipments used in plants.

3.1 Indoor test of asphalt mixtures by location

As in Table 2, the result of mix design report from plants in different locations was compared with the result of indoor test performed in the lab. Measured density showed -0.052～0.063 of deviation, and the plants showed a value 0.006 lower on average. Theoretical density showed -0.003~0.032 of

deviation, and the plants had values 0.021 lower than the lab on average. From the results, it could be inferred that the air-void has -2.0~2.3% of deviation. Assuming permissible error range as ±1.5% when compared to lab test results, five locations were out of the permissible range.

Table 2 Comparison of Plant Mix Design Report and Lab Test

Location	Measured Density (g/cm^3)			Theoretical Density (g/cm^3)			Air-Void (%)		
	Plant	Lab	Dev.	Plant	Lab	Dev.	Plant	Lab	Dev.
A	2.484	2.456	-0.028	2.564	2.596	0.032	3.1	5.4	2.3
B	2.411	2.453	0.042	2.468	2.500	0.032	2.3	1.9	-0.4
C	2.366	2.324	-0.042	2.453	2.459	0.006	3.6	5.5	1.9
D	2.365	2.412	0.047	2.463	2.471	0.008	4.0	2.4	-1.6
E	2.363	2.378	0.015	2.455	2.486	0.031	3.7	4.3	0.6
F	2.401	2.464	0.063	2.512	2.524	0.012	4.4	2.4	-2.0
G	2.399	2.347	-0.052	2.517	2.515	-0.002	4.7	6.7	2.0
Mean	2.398	2.404	0.006	2.489	2.509	0.021	3.7	4.2	0.5

3.2 Comparative test on maximum theoretical density tester by location

The result of testing the property of asphalt mixtures by location showed a difference between the values obtained from the plant and the lab for the same mixtures. To identify the cause, samples of the mixtures were created and compared with the testers used at plants.

The result of test showed maximum theoretical density distribution of 2.473～2.529 as in Table 3. In location D, the value was 2.529, which had the highest deviation of -0.038. In location F, the value was 2.473, with the lowest deviation of 0.019. When the permissible error range between the tester in the plant and the equipment used in the lab was assumed as ±0.02, one location was out of the range of permissible error.

Table 3 Deviation among Theoretical Density Testers (Lab Equipment vs Plant Equipment)

Classification	Maximum Theoretical Density (g/cm^3)			Deviation
	1	2	Mean	
Lab	2.492	2.492	2.492	
A	2.518	2.478	2.498	-0.007
C	2.480	2.486	2.483	0.009
D	2.516	2.543	2.529	-0.038
F	2.470	2.476	2.473	0.019
G	2.518	2.503	2.511	-0.019

Test value of maximum theoretical density for the same asphalt mixtures showed a deviation of -0.038～0.019 for different testing equipments. When the effect on air-void was calculated using deviation values, the measured density was assumed to be 2.400 as in Table 4, and maximum theoretical densities

2.473 and 2.529 that resulted from the deviation between equipments were applied. The result showed maximum air-void deviation of 2.1%, proving the same asphalt mixture can be evaluated differently depending on the tester.

Table 4 Changes in Air-Void by Deviation in Theoretical Density

Classification	Measured Density	Theoretical Density	Air-Void	Note
1	2.400	2.492	3.7	Lab
2	2.400	2.529	5.1	Location D
3	2.400	2.473	3.0	Location F

3.3 Test on mixtures by the date manufactured in plants

To check the conditions of quality control on asphalt mixtures, 22 sets of the same asphalt mixtures manufactured over a three-month period at Plant A were collected and analyzed to obtain the measured density, maximum theoretical density, and air-void of the asphalt mixture. Table 5 is a mix design test report on the same mixture manufactured at Plant A, and Table 6 is the result of testing measured and theoretical densities of the asphalt mixture by manufacturing date.

Table 5 Test Report on Mix Design of Mixtures from Plant A

Classification	Measured Density (g/cm^3)	Theoretical Density (g/cm^3)	Air-Void (%)
Test Report	2.458	2.564	4.1

Table 6 Test on Maximum Theoretical Density by Production Term

Production Term (day)	Measured Density (g/cm^3)	Theoretical Density (g/cm^3)	Air-Void (%)
1	2.462	2.594	5.1
2	2.488	2.587	3.8
3	2.461	2.598	5.3
4	2.444	2.557	4.4
5	2.497	2.558	2.4
6	2.502	2.572	2.7
7	2.501	2.556	2.1
8	2.453	2.548	3.7
9	2.466	2.538	2.8
10	2.470	2.564	3.7
11	2.455	2.566	4.3
12	2.513	2.558	1.7
13	2.496	2.582	3.3

14	2.498	2.539	1.6
15	2.496	2.562	2.6
16	2.494	2.545	2.0
17	2.512	2.558	1.8
18	2.484	2.563	3.1
19	2.478	2.550	2.8
20	2.487	2.562	2.9
21	2.498	2.577	3.1
22	2.460	2.555	3.7
Mean	2.482	2.563	3.1
Standard Dev.	0.020	0.016	1.034

Based on the results described in mix design test report on mixtures from Plant A, which showed measured density of 2.458, theoretical density of 2.564, and air-void of 4.1%, measured and theoretical densities that correspond with air-voids 3% and 5% were calculated. The measured densities that correspond to air-voids 3% and 5% were 2.487 and 2.436, and theoretical densities that satisfied air-voids 3% and 5% were 2.534 and 2.587. Tables 7 and 8 shows the measured and theoretical density values that correspond to air-voids 3% and 5%.

Table 7 Measured Densities that Correspond to Air-Voids 3% and 5%

Air-Void(%) / Density(g/cm^3)	3.0	4.1	5.0
Measured Density	2.487	2.458	2.436
Theoretical Density	Fixed at 2.564		

Table 8 Theoretical Densities that Correspond to Air-Voids 3% and 5%

Air-Void(%) / Density (g/cm^3)	3.0	4.1	5.0
Measured Density	Fixed at 2.458		
Theoretical Density	2.534	2.564	2.587

Figure 5 is a graph that expresses changes in measured density by the manufacturing date. Standard measured density is the measured density from mix design test report 2.458(g/cm^3). Upper and lower limits are measured densities that correspond to air-voids 3% and 5%. The upper measured density limit was 2.487, and the lower measured density limit was 2.436. Measured density of a total of 11 sets of mixtures satisfied the standard, 50% among the total of 22 mixtures.

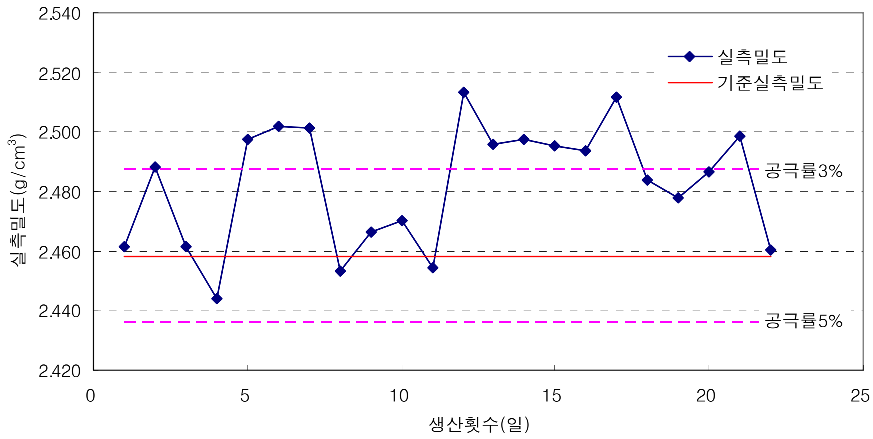


Fig 5 Changes in Measured Density by the Date Manufactured

Figure 6 is a graph that expresses changes in maximum theoretical density by the manufacturing date. Here, the standard theoretical density is the maximum theoretical density from the mix design test report 2.564(g/cm^3). Upper and lower limits are maximum theoretical densities that correspond to air-voids 3% and 5%. The upper maximum theoretical density limit was 2.587, and the lower maximum theoretical density limit was 2.534. As in the figure, 20 among the total 22 mixtures satisfied the maximum theoretical density standard (91%), and most mixtures that were analyzed fell within the range of maximum theoretical density standard.

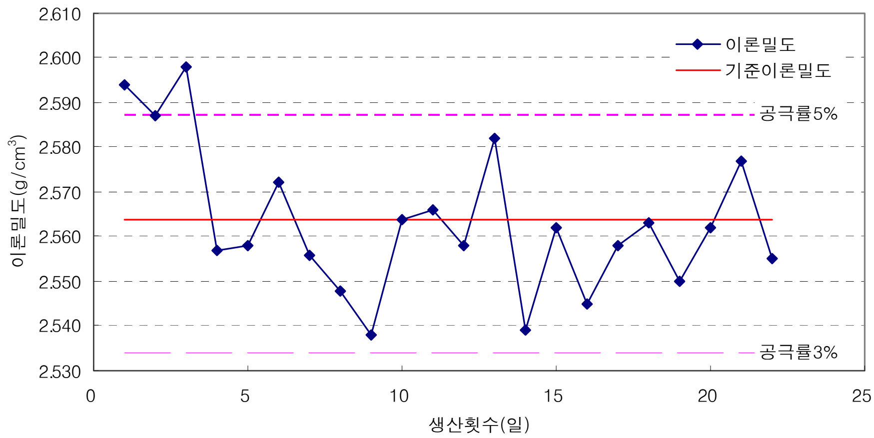


Fig 6 Changes in Theoretical Density by the Date Manufactured

4. Development and Application of the Field Compaction Evaluation Method

In the 1990s, plastic deformation frequently occurred in the highways. To cope with the problem, experts of the field conducted researches and made efforts to prevent plastic deformation, and plastic deformation was greatly reduced as a result. As in Figure 7, insufficient compaction appears as the major cause in excessive air-void in asphalt mixtures, which leads to pavement

damages, according to the result of analyzing the causes of recent damages to the asphalt concrete pavements.

Inadequate compaction leads to larger air-void, making rainfall enter the pavement. This penetration of pavement in turn creates pot-holes from the excess pore water pressure initiated by increased vehicle load. In cases of bridge deck pavements, rainfall penetrates into the slav, and the residual water affects the structure.

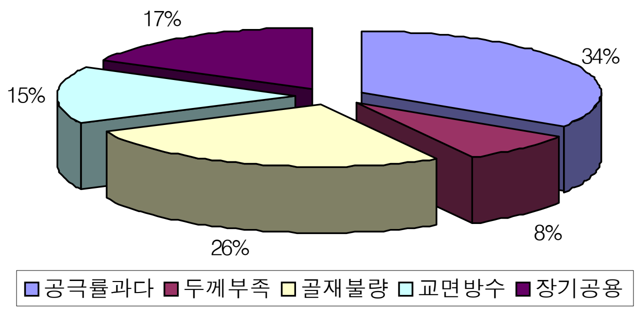


Fig 7 Causes of Asphalt Pavement Damage

4.1 Compaction criteria and the evaluation

In other countries, equipments for core collection and radioactive isotope are concurrently used to control the field compaction of asphalt pavements. Preventive quality control of asphalt pavements are performed in these countries: the compaction density is evaluated on-site, and this enables immediate correction of the problem using the feedback.

In South Korea, compaction density is measured using the mixtures approved by the supervisor which are manufactured in accordance with the field mixing specification. The mean value of three marshal specimens measured indoor are used as the standard density. As for the compaction standard on dense-grade asphalt pavements, it must exceed 96% of the specified compaction standard. For SMA pavements, 97% or higher needs to be achieved. Cores must be collected on-site to calculate the field compaction density, and this procedure consumes approximately 2~3 days, making prompt on-site correction and response impossible.

According to the regulations of South Korea related to the safety in radioactive ray use, a different regulation is applied for using radioisotope (RI) over 100mCi; it is virtually impossible to use a RI. Therefore, a method of measuring field compaction density on-site needs to be developed to allow prompt on-site compaction control.

4.2 Development of field compaction measuring instrument

Compaction management is crucial for preventive quality control of asphalt pavements. However, the current compaction management system consumes 2~3 days in measuring the field compaction, making it impossible to implement preventive quality control. In this study, the time

required for the testing in each step was reduced to enable the measurement of field compaction within an hour of completing the compaction, which in turn allows for preventive quality control.

While keeping the principles and the concept of existing measuring means for field compaction density, the measuring means was enhanced to measure the field compaction within an hour to enable preventive quality control of asphalt pavements. As in Table 9, core collection was difficult when coring was performed before the asphalt pavement has completely cooled down and required 12 hours of waiting time. With the new method, ice can be put inside the water supplied to the core machine to compact the asphalt mixture, and this allows the core to be collected immediately. Moreover, a steam blower can be used to dry water to promptly measure the dry weight.

Table 9 Comparison of Field Density Measurement Methods (Previous vs New)

Classification	Previous Field Compaction Density Measurement (KS F 2446)	Enhanced Field Compaction Density Measurement
Core Collection	. Cores are collected once the asphalt pavement is completely cooled in a natural condition (12 ~ 24 hours)	. Ice is put in to the water supplied to the core machine to collect cores (10 ~ 20 minutes)
Dry Weight Measurement	. Specimen is dried in an oven and measured for dry weight (24 hours)	. Dried using a dryer designed for specimens and measured for weight (10 minutes)
Underwater Weight Measurement	. Specimen is immersed in an indoor testing water tank and measured for underwater weight (10 minutes)	. Immersed in water using a field density test equipment and measured for underwater weight (10 minutes)
Surface Dry Weight	. After measuring the underwater weight, the surface is dried to measure surface dry weight (10 minutes)	. Same as the left
Time Required	. Over 48 hours	. Within an hour

4.3 Field compaction evaluation and field application

The result of investigating six locations to determine the field compaction management and air-void in the construction sites is as Table 10. Initial air-void after compaction needs to be within 8%, and calculating the air-void based on the theoretical density suggested from the site all resulted in less than 8%, inferring that all compaction criteria were met. However, lab test result on theoretical density showed an outcome of two locations not falling within the 8%. The results indicate compaction management on-site appears to be in control but does not always satisfy the target air-void.

The reason behind this result is inability to take corrective measures due to the 24~48 hours required for the compaction measurement when the existing compaction management method is used. The experiments in this study allowed the measurement of consumed compaction to be taken within an hour of the field compaction, furthermore enabling the preventive quality control.

Table 10 Results of On-Site Application of Field Compaction

Location	Measured Density (g/cm^3)		Theoretical Density (g/cm^3)		Air-Void (%)		
	Field	Lab	Plant	Lab	Field	Lab	Deviation
A	2.401	2.381	2.564	2.3604	6.4	8.6	2.2
B	2.344	2.338	2.468	2.508	5.0	6.8	1.7
C	2.285	2.265	2.463	2.478	7.2	8.6	1.4
D	2.342	2.338	2.477	2.531	5.4	7.6	2.2
E	2.317	2.315	2.455	2.493	5.6	7.1	1.5
F	2.325	2.312	2.455	2.493	5.3	7.2	2.0
Mean	2.336	2.325	2.480	2.518	5.8	7.7	1.8

5. Conclusion

In this study, materials, plants, and quality control conditions were analyzed at seven construction sites to analyze the problems in mix design, manufacturing and construction processes for the purpose of reducing damages to asphalt pavements. Key conclusions from the study are as follows.

⑴ To discover the ratio of flat or elongated particles in aggregates, 15 samples (nine crushed stone aggregates and six SMA aggregates) were collected and analyzed. Of the seven locations, three had less flat or elongated particles in aggregates, and SMA aggregates were analyzed to be under sound quality control. Aggregate rank was assigned to the collected samples, and of the total, first rank was 33%, second rank was 40%, and third rank was 27%, indicating flat or elongated particles in aggregates were not thoroughly managed.

⑵ To analyze the density and absorptance of the aggregates, 20 samples were collected. Coarse and fine aggregates analyzed in the study showed the density of most to fall within the standard 2.5, except for one location. Likewise, the absorptance of most coarse and fine aggregates showed a value lower than the standard 3.0% except for one location.

⑶ As a result of analyzing the aggregate size, two locations (C and D) satisfied the size specification in cold bins, and five locations (A, B, E, F, and G) were out of the specification range. In case of hot bins, all locations failed to meet the size specification, but five locations (A, B, D, F, and G) had relatively similar size as the specification. The reason for unsatisfactory aggregate size appears to be the lack of separate asphalt mixture aggregates since single-grade aggregates need to be used.

⑷ Comparison between the mix design test report from plants and the lab test result showed a difference in measured and theoretical densities, and the resulting difference in air-void showed approximately 0.4~2.3% of deviation. Verification of the test results from the field showed that five locations were out of the permissible error range.

⑸ The test value on maximum theoretical density of the same asphalt mixtures showed deviation of -0.038～0.019 for different testing equipments. The deviation values were used to calculate the

degree of influence the air-void imposes, and by field, maximum of 2.1% air-void difference was analyzed to occur.

⑹ The result of analysis on the compaction management conditions in the fields, all fields appeared to satisfy the compaction management criteria according to the on-site test results. However, the result of test conducted in this study showed that two locations failed to meet the criteria, indicating inadequate quality control in fields.

⑺ In this study, a field compaction assessment method was developed and applied for better compaction management. Comparative analysis of the field compaction test and indoor compaction density on the density after changes in asphalt content showed slightly larger field compaction density compared to the KS F 2446 testing method. However, the error range appeared as within 0.3%, indicating high accuracy.

⑻ On-site density measured in the site where asphalt pavement was constructed was compared with the indoor compaction density. The result showed a slightly larger field compaction density compared to the KS F 2446 testing method, but the error was measured to be within 0.5% range, indicating high in-field applicability.

⑼ As a way to apply "field compaction density testing method" which enables preventive quality control, one set per 30a needs to be sampled (enforcement ordinance of the Construction Technology Management Act), and field compaction density should be measured for quality control. Lastly, indoor testing in accordance with the KS F 2446 for quality inspection appears to be the ideal method.

⑽ Comprehensive result of the analyses performed in this study indicates the following four categories require in-depth quality control: In the order of least effective quality control, air-void, flat or elongated particles in aggregates, aggregate size, and compaction management require a better quality control.

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